Gas-Cooled Reactor-Based Transmutation

Status Report

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Summary of Work

- **Evaluating Reactor-Based Transmutation using gas-cooled, graphite-moderated (GCR) systems:**
  - **Developing a deployment strategy, and a deep-burn core design, and matching the core design to TRISO fuel capabilities.**
- **Design to maximize GCR TRU waste destruction with minimum reprocessing:**
  - **Utilize the high burnup capability of TRISO fuel, and fertile free core operation to minimize the complexity of recycle operations.**
- **Design based on the commercial GCR to minimize development cost**
- **Results indicate that, for the first tier, 77% total TRU waste and 95% fissile destruction should be feasible in a fuel cycle with up to 18 months between refuelings.**

The Gas-Cooled (GCR) Transmutation Program

There are three elements to this program:

1) Strategy

- **Develop a deployment strategy for the GCR which provides for an economical and practical use of these systems for waste transmutation.**

2) Reactor-Based Transmutation Studies

- **The GCR has several transmutation options.**
- **This year's effort is focused on the deep burn properties of the TRISO fuel.**
- **Determine the TRU destruction levels and mass flows for this design.**

3) Fuel Development

- **Match the deep burn design to the TRISO particle capabilities.**
- **Interface with ongoing TRISO particle development program.**

Gas-Cooled reactor transmutation provides a flexible and economic approach to this problem, which can be combined with other methods.

The GCR is Flexible and Provides Options for Waste Transmutation

- **Deep-Burn Transmutation:**
  - Maximize TRU destruction in a single in-core irradiation .
  - Requires only one proliferation-free reprocessing step.
  - Uses two separate fuel particles:
    - » Driver fuel (DF) of LWR Np + Pu.
    - » Transmutation fuel (TF) of LWR Am + Cm, and the TRU waste from the discharged DF.
  - Alternative Fuel Cycle:
    - » Recycle the discharged DF TRU waste back into the UREX process.
    - » Minimal impact on UREX process.
    - » Eliminates the extra separations step (needs head-end step only).
- **Destruction of Waste Plutonium Only:**
  - Use only LWR discharge plutonium and neptunium as the fuel.
  - Use erbium as the burnable poison if needed.
  - Can be used as a stand alone option or to allow development of the TF.
  - Destroy remaining TRU in second tier
- **No Separation of Plutonium:**
  - Single fuel particle of LWR TRU.

The GCR System Supports the Transmutation Program

- Provides a fertile free reactor for waste plutonium destruction
- Provides a passively safe transmutation system.
- Based on commercial plant design to minimize development costs, and encourage utility acceptance.
- High temperature operation for efficient electricity production, or hydrogen production.
- Requires fewer and smaller second tier systems.
- Minimum reprocessing requirements to improve overall economics, and minimize waste production.

Goals for the Deep-Burn Reactor-Based Transmutation Study

- **Maximize total TRU destruction without repeated reprocessing**
  - *Use two fuel types to maximize burnup*
  - *Goal is >75% total TRU destruction in first tier.*
- **Maximize Fissile Plutonium Destruction**
  - *Use fertile free fuel and whole core TRU load*
  - *Goal is >90% fissile plutonium destruction in first tier.*
- **Meet TRISO Fuels Technology program requirements:**
  - *Maximum fast fluence $\leq 8x10^{25}$ n/m^2 (E>0.18MeV).*
  - *Meet fuel performance requirements based on fuel models.*
- **Base Design on Commercial Gas-Cooled Reactor:**
  - *Same components, and similar reactor operating conditions (e.g. coolant temperatures and pressure) to minimize development costs.*
  - *Similar core operating and safety envelope.*
  - *Accept a wide range of feed compositions*
  - *Goal is a fuel form which could be used in a commercial plant.*

Gas-Cooled Transmuter Deployment Strategy

- Assume availability of a GC-MHR demonstrator in 2010-2012 that
  - Demonstrates economics, siting, and licensing
  - Operates on industry supplied Uranium Oxycarbide TRISO fuel
  - Demonstrates Hydrogen or electricity generation
- TRISO transmutation fuel would be demonstrated in this same reactor, and the technology would be applied to subsequent GC-MHR installations (4-packs) as built
- An approach to minimize startup cost has been envisioned
  - A hybrid, bench scale separation process, without DF recycle, would be applied to produce material for initial Lead Test Assemblies (LTA's)
  - A small scale fabrication facility would be used to produce LTA's, with potential to support the demonstrator reactor.
- Evaluate use of existing facilities to the maximum extent possible that would support full core production and subsequent development

Deep Burn Material Flow Diagram

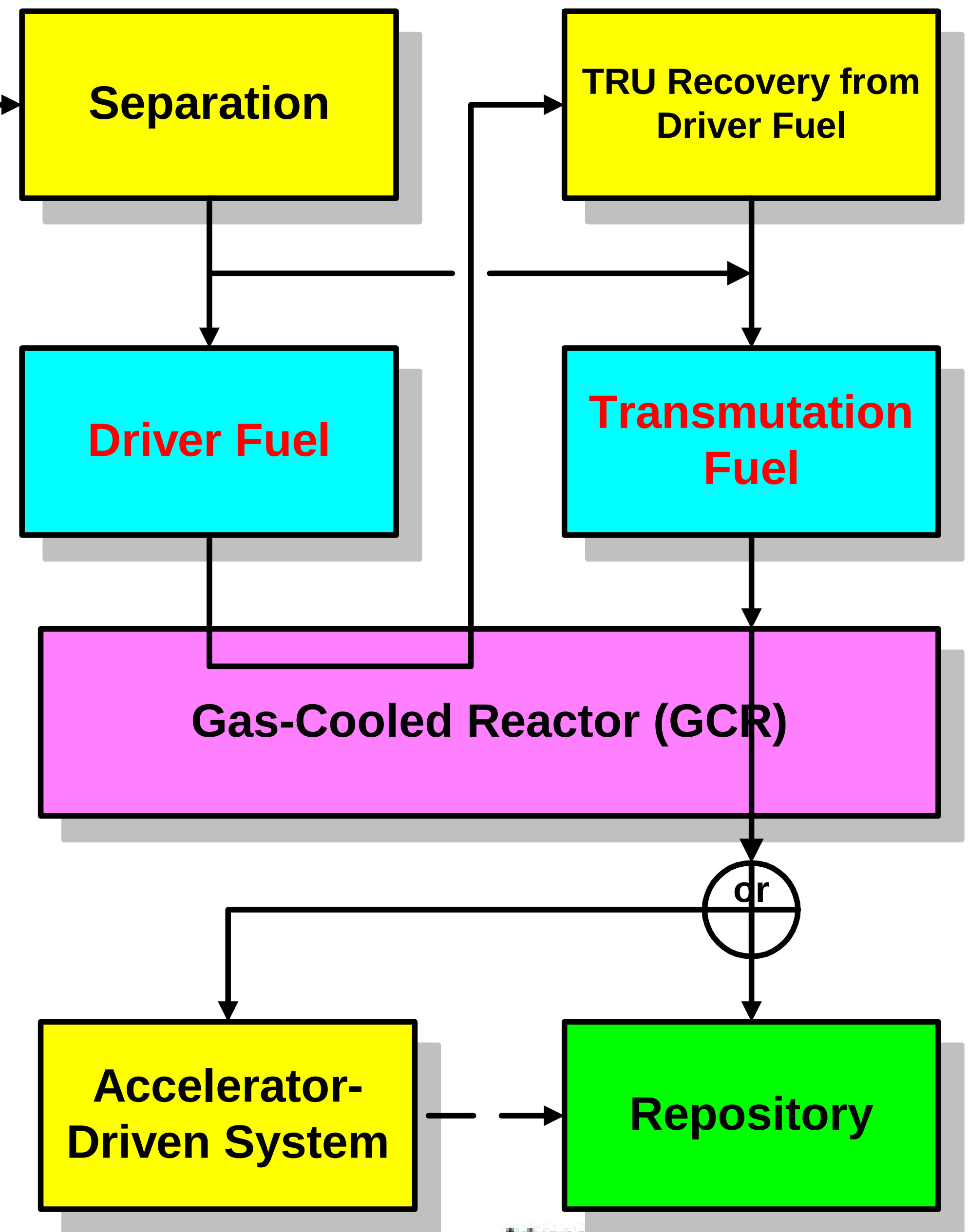
2 Fuel types

One-pass transmutation

Maximum fissile plutonium destruction in a single pass

Possibility for additional transmutation in a second-tier system

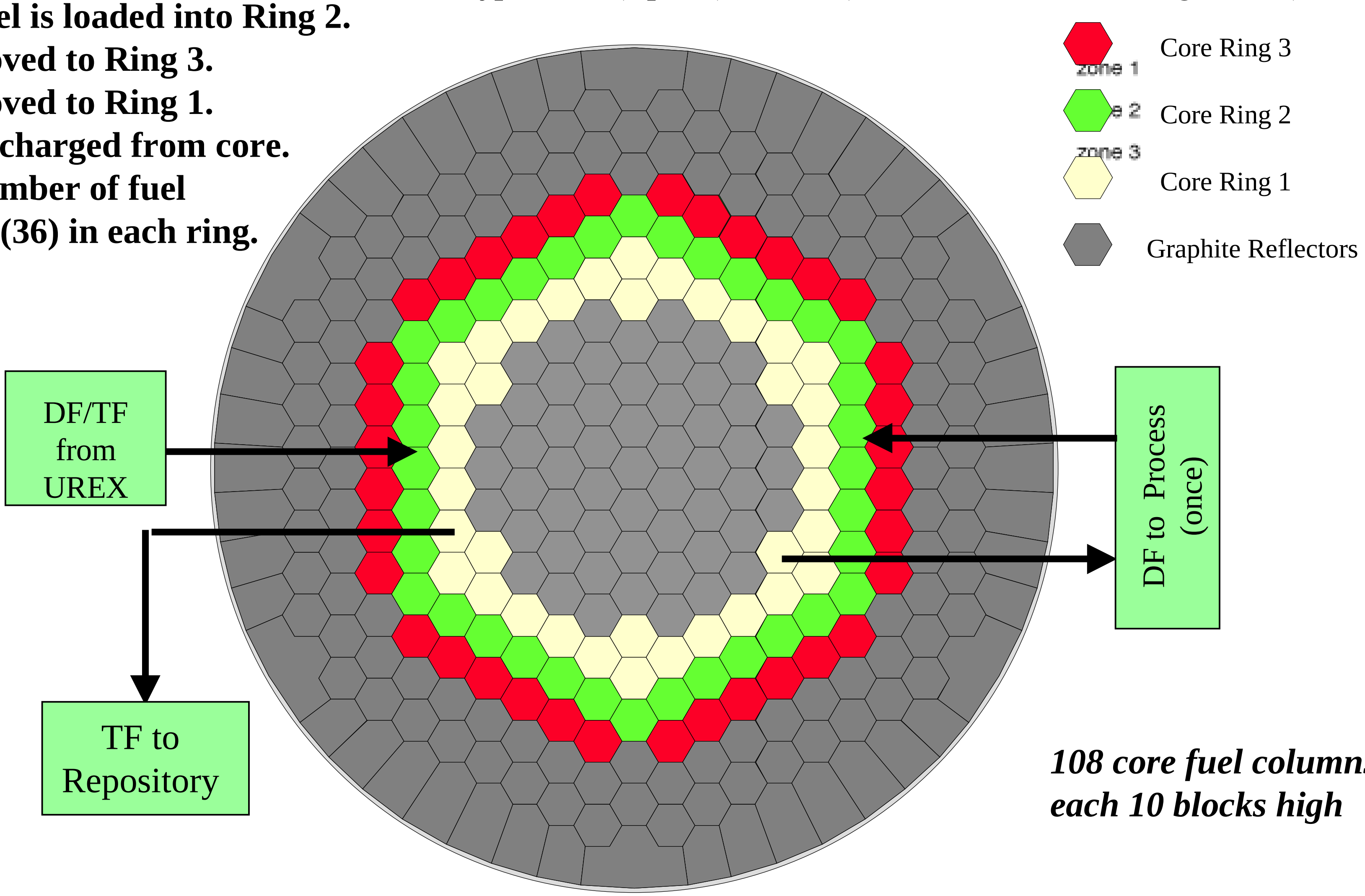
Possibility to dispose of residual material in highly resistant coated particles



“3 Ring” GCR core for Waste Transmutation

3 Segment Operation:-
- **Fresh fuel is loaded into Ring 2.**
- **Then moved to Ring 3.**
- **Then moved to Ring 1.**
- **Then discharged from core.**
- **Same number of fuel columns (36) in each ring.**

2 Fuel types - DF (Np+Pu) and TF (Am+Cm, and DF discharged TRU)



108 core fuel columns each 10 blocks high

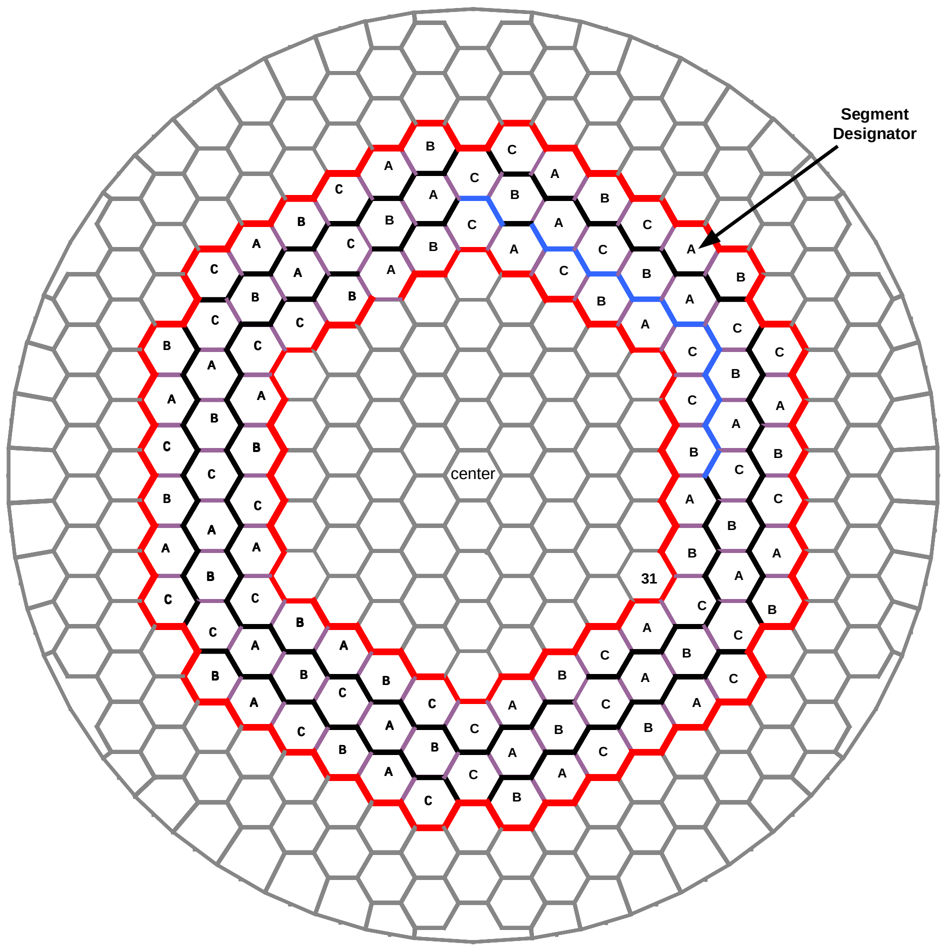
Advanced Accelerator Applications

“Distributed Segment” GCR Core for Waste Transmutation

3 symmetrically distributed fuel segments (A, B, C)

2 Fuel types - DF (Np+Pu) and TF (Am+Cm, and DF discharged TRU)

Fuel in each segment stays
In the same core location
Throughout its life.



- *102 core fuel columns each 10 blocks high.*
- *36 columns in outer ring.*
- *36 columns in middle ring.*
- *30 columns in inner ring.*
- *34 columns per fuel segment.*

Transmuter Study Results to Date

- **12 Month Refueling Interval:**
  - 3 year residence time.
  - 95% fissile Pu and 77% total TRU destruction.
  - 468 GWD/MTM Pu particle burnup.
- **18 Month Refueling Interval:**
  - 4.5 year residence time.
  - 96.5% fissile Pu and 80% total TRU destruction.
  - 500 GWD/MTM Pu particle burnup.
- **24 Month Refueling Interval:**
  - 6 year residence time.
  - 97.5% fissile Pu and 83% total TRU destruction.
  - 659 GWD/MTM Pu particle burnup.
  - Equilibrium critical cycle not established.
- **Deep-Burn Results being validated by Framatome.**

Planned Work for Rest of FY-02

- Complete draft deployment strategy
- Complete fuel cycle results validation
- With Framatome, complete verification of physics analysis and fuel cycle.
- Confirm negative temperature coefficient.
- Complete thermal/hydraulics and stress analysis
- Complete fuel performance evaluation
- Develop licensing issues for a GCR with TRU fuel.

Looking Forward

- **In FY02, we are maximizing overall TRU destruction with a design that looks like a commercial reactor.**
- **Allow for a phased development of the TRU fuel:**
  - **Plan allows initial operation with DF (Np+Pu) particle, and a burnable poison if necessary.**
  - **Phase in TF as qualification is completed.**
- **Need to provide deployment incentives for the utility industry:**
  - **TRU fuel that can be used in a commercial reactor, like MOX.**
  - **Meet commercial licensing and operating requirements**
  - **Competitive fuel cycle from a refueling interval standpoint.**
  - **Flexibility to adapt to changing input fuel forms.**

Proposed FY03 Activities for GA, ORNL, and WSRC in WBS 1.50

- **Select most economical tier-1 GCR fuel cycle: ($1.2M)**
  - Deep-Burn fuel cycle.
  - Pu only destruction fuel cycle.
  - No plutonium separation fuel cycle.
- **Calculate and verify critical parameters for safety, performance, and operability for this cycle: ($1.3M)**
  - reactivity, heat loads, fuel requirements, etc.
- **Assess material flows, costs, proliferation risk, and residual toxicity for this cycle. ($800K)**
- **Define discharge for the second tier. ($400K)**
- **Develop detailed deployment strategy. ($1M)**
  - compatible with commercial reactor deployment.
  - allow for phased TRU fuel qualification.
  - Evaluate incentives for commercial utility use of TRU fuel.

Total $4M